Two Classes of Solar Flares

Suryanarayana Sheshagiriyappa Gadikere
Indian Institute of Astrophysics
Koramangala, Sarjapura Road, Bangalore-560034, India
suryanarayana@iiap.res.in
(Submitted on 06.07.2021; Accepted on 03.09.2021)

Abstract. Active regions where flares alone occur and flares with coronal mass ejections (CMEs) occur display substantial differences in behaviour and morphology. The higher peak flux of the soft X-ray (SXR) emission is an important characteristic of the flares that occur with CMEs. Therefore, flare peak flux could be a strong indicator that there could be two classes of flares – one with associated CMEs and the other without CMEs. This classification is distinct from the SXR flare classes A to X.
Key words: Sun, Solar flares, Flare classes, SXR peak flux, Coronal mass ejections, Methods: statistical

1. Introduction

Flares occur with and without associated CMEs (Tandberg-Hanssen and Emslie 1988, Green et al. 2001). Several studies highlight distinct aspects of active regions (ARs) where both flares and CMEs occur in contrast to ARs where flares alone occur (Green et al. 2001).

A study by Brosius and Holman (2012) reports that the flare accelerated non-thermal particles trigger the heating of the chromosphere, inducing evaporation in the chromosphere resulting in the hot, dense, plasma filling magnetic loops. Assuming that such a swelling of magnetic loops would cause catastrophic detachment of coronal loops on all or some occasions resulting in the occurrence of CMEs, it is inferred that the longer duration and higher peak flux emission could be a strongly associated characteristic of the flares occurring in association with CMEs. By this, we do not suggest that flares drive CMEs. Further, quite a few short duration flares do have associated CMEs.

The power-law indices for flares without CMEs are steeper than those for flares with CMEs (Yashiro et al. 2006). This result indicates that there exist better association between flare duration and peak flux for flares without CMEs. This is not the case for flares with CMEs, indicating that these flares are probably of a different class.

A close association exists between the main energy release of the associated flare and the impulsive acceleration of a CME in the inner corona. Also, the CMEs associated with the long-decay time flares (otherwise known as flares of long-duration) are known to experience acceleration further to flare impulsive-phase, even when some of them have already reached a high speed during post-impulsive acceleration phase while not showing a deceleration that is expected from the aerodynamic drag by the background solar wind (Chen et al. 2011).

The presence of two ribbon flares in H alpha is an important characteristic of CME producing filament eruptions while this property was not found in the flares without CMEs (Choudhary and Moore 2003). However, it is also pointed out that the presence of ribbons does not guarantee CME associated flare emission. In this connection, it has been reported that ribbon-separation velocity, as well as larger ribbon separation, appear to be well associated with CME associated flares. Even though Geostationary Operational Environment

Satellite (GOES) soft X-ray (SXR) flux is reported to be demonstrating good association with ribbon separation, contrary result is also reported that ribbon separation velocity is not well associated with GOES flux (Hinterreiter et al. 2018). The phenomenon is quite complex.

The growth of arcade associated with the emergence of flux and CME, the particle acceleration in flares and the large-scale acceleration of CME are strongly coupled (Liu et. al. 2010a).

The displacement parameter, which is the distance between the flare region and the flux-weighted center of magnetic region is much larger for the CME occurring ARs than for the confined flares (Wang and Zhang 2007).

The CMEs generally occur from large source regions compared to flares (Harrison 1995). This indicates that such flares may contain higher energy.

The concept of free magnetic energy is important because energy in such ARs could be the maximum during a CME, solar flare or a filament eruption (Aschwanden 2013). This is because the time profile of GOES flux and free energy, and also GOES flux and free energy ratio (free energy/potential energy), shows good correlation (Aschwanden 2015). Further, the linear least square fits between linear and logarithmic values show good association, displaying an exponential or a power-law function (Aschwanden 2013). It is observed that, generally, CME associated flares emit higher peak flux (Suryanarayana and Balakrishna 2017). The higher free energy has been found to be essential where both flares and CMEs occur, whereas a flare or a CME alone may occur if the free energy is less (Lin 2004).

The complex ARs, as indicated by sunspots of $\beta\gamma$ type, tend to emit flares with CMEs 90 % of the time, whereas ARs of the type α or β are known to emit only flares (Chen et al. 2011). In other words, the emphasis is on the ARs complexity leading to increased CME productivity. Several ARs parameters are significantly higher if there is an associated CME (Cheng et. al. 2011 and references therein). The occurrence of higher intensity flares in ARs with enhanced parameters (tilt angle, total flux, length of the strong-field and strong-gradient on the main neutral line and effective distance which is an indication of magnetic complexity) is highlighted in other studies too (Guo et. al. 2007).

Similarly, several parameters of ARs associated with flares of higher peak flux were found especially associated with high speed CMEs (Su et. al. 2007). We also note that for a given peak flux, flares generally last for a longer duration if they are confined events (Wang and Zhang 2007). In other words, for a given flare duration, the flares attain higher peak flux if they are associated with CMEs.

In other words, on a comparative scale, for a given flare duration, higher peak flux is often the case when a CME occurs along with a flare (Suryanarayana and Balakrishna 2017). Thus, the free energy that is accumulated (Cheng et. al. 2011 and references therein) is released swiftly if flares occur with CMEs, which amounts to higher peak flux. The new flux emergence in complex ARs is often the case when flares and CMEs occur (Green et. al. 2003) in comparison to flare occurrence alone. Hence, new flux emergence may be construed as aiding the occurrence of higher peak flux flares in association with the CMEs.

While the long duration flares are known to be highly associated with CMEs, increasing duration coupled with higher peak flux is found to be very essential for an associated CME (Suryanarayana and Balakrishna 2017). This leads to the view that CMEs occur probably because of a result of an independent process. In other words, the magnitude of energy build up, as seen by the flare duration, seems less important.

It has been found that CMEs occur increasingly if the SXR flux is increasing (Nitta et. al. 2014). In particular, the result as indicated in the figure in that paper brings out the fact that distinctly higher peak flux is emitted for most flares across all durations when these flares have associated CMEs in contrast to flares without CMEs (Suryanarayana and Balakrishna 2017).

It is suggested that a prediction is possible with a 95% confidence that CME will be observed when the thresholds of peak flux of the flare is 6.0 x 10^{-5} Wm^{-2} or more (Andrews 2003).

The CME kinetic energy and velocity and the SXR peak flux values of flares are correlated (Burkepile et al. 2004, Hundhausen 1997, Chen and Zong 2009). The coronal plasma heating from the reconnection region is also suggested to be important to the CME kinetics where the flare also occurs (Jain et. al. 2010). The obvious inference is that more flux would be emitted in flares with CMEs.

The reconnection leads to energy of the magnetic field being converted in the corona, resulting in the heating of plasma and acceleration of the particles. Thus, the dominant process of conversion of the energy due to magnetic field heats the coronal plasma of the reconnected loops that may drive the CMEs to increased speeds (Jain et. al. 2010).

It is also suggested that the velocity of CME and the peak flux of X-ray emission is enhanced than that between the time-integrated X-ray flux and the CME velocities of associated flares (Chen and Zong 2009). The association of high flux value flares to the fast CMEs apparently renders them as good candidates for acceleration of particles (Suryanarayana 2012 and references therein).

Thus, whether the flare flux in general and peak flux in particular drives the CMEs or not, the high peak flux serves as an indicator of the underlying cause that triggers CMEs. In other words, the foregoing discussion presents for a compelling argument for a sharp difference in characteristic of flares having associated CMEs in comparison to flares that are not associated with CMEs.

Hence, we examine whether the flares occurring with and without CMEs can be regarded as comprising of two classes.

The reconnection of magnetic fields is believed to trigger both flares and CMEs. In other words, magnetic reconnection is the common attribute of flares with and without CMEs. Hence, we compare flares of same duration so as to know the difference in their peak flux emissions. This is also aided by the fact that the CME occurrence rate increases rapidly with flare duration (Sheeley et al. 1983, Kahler et. al. 1989). Hence, flare duration serves as a reasonable parameter to compare the difference, if any, between the peak flux values of flares occurring in association with the CMEs as opposed to flares with no associated CMEs.

2. Data

We make use of the Solar Geophysical Data (SGD) archive that lists the flares observed by Geostationary Operational Environment Satellite in SXR in the wavelength bands of 0.1-0.8 nm[1]. The flare duration is obtained using the start and end times reported. The flare peak flux values are also indicated in the archive.

It is reported that the simple temporal association of flares with CMEs within 2 hours time window from the CMEs yields 85 % association with CMEs (Cheng et al. 2010, Cheng et. al. 2011, Harrison 1991, Harrison 1995). We collect a total of 11,822 flares from the years 1999 to 2002. In this statistics, 3462 flares are associated with CMEs that occur within ±2 hour from the time of first observation of CMEs. The remaining 8360 flares do not have associated CMEs meeting this criteria and hence are regarded as flares without associated CMEs.

The data of CMEs is from the SOHO (Solar and Heliospheric Observatory) LASCO (Large Angle and Spectrometric Coronagraph) [2]. The Wind Waves (WW) flare events are obtained from the WW archive [3]. The WW list is obtained by identifying ARs, solar radio type II bursts, flares and CMEs (Gopalswamy et al. 2018). Hence, these flare - CME associations are quite stringent (Gopalswamy et al. 2019). This is a sub set of flares associated with CMEs.

The flares from WW list are generally of very high peak flux. The flares associated with CMEs, as obtained from the simple temporal association, could be consisting of some flares that are not necessarily associated with CMEs. This may somewhat affect the actual average peak flux of such flares. This has possibly resulted in the lower average peak flux of flares that are from the simple temporal association, compared to peak flux values of flares from the WW list. However, the use of simple temporal association list of flares associated with CMEs is necessary for the sake of completeness of data. Further, we are not looking for an exact value of difference in the peak flux between two set of flares.

Figure 4, top panel, in the paper of Liu et al. (2010b) gives an idea about the propagation direction of CMEs which would be largely between -2 to + 5 degrees around The Sun-Earth line. In other words, a CME is expected to generally propagate radially outward from the source region. This means, a CME originating on the far side of the Sun would most often be propagating on the far side. Hence, the possibility of an invisible side flare being associated with a CME observed by the SOHO LASCO is quite small.

Since, the simple temporal association ensures that the flares are considered as without associated CMEs if no CME has occurred within the 2 hours time window, such flares can be considered as mostly without really having any associated CMEs. On the other extreme, the WW flares are considered as associated with CMEs on the basis of a reasonably strict criteria. In between, the flares considered as associated with CMEs purely on the temporal association may have some doubtful events. However, this set along with WW list

[1] ftp://ftp.ngdc.noaa.gov/STP/SOLAR DATA/SGD_PDFversion/
[2] http://cdaw.gsfc.nasa.gov/CME_list/ archive
[3] https://cdaw.gsfc.nasa.gov/CME_list/radio/waves_type2.html

will still provide a reasonable indication about the distinctness of these flares, compared to flares without CMEs.

3. Analysis and Results

Since magnetic reconnection has been strongly believed to trigger flares as well as CMEs, and the rate of CME occurrence increases with the flare duration (Suryanarayana and Balakrishna (2017) and the references therein), we compare the peak flux of flares with and without CMEs in terms of flare duration.

We bin the flare durations and the corresponding peak flux values in the range of 5 minutes of flare duration. This follows the method used in an earlier paper (Suryanarayana and Balakrishna 2018). We plot these values as grouped bar plots.

We find that the flares associated with CMEs have higher peak flux values in comparison to flares with no CMEs. The result is shown in Fig.1. The flares from the WW list demonstrate the phenomenon in a very pronounced manner.

The error bars plotted on each bar has been computed as follows. The square root of the number of points for each bin is obtained and the same is divided by its standard deviation.

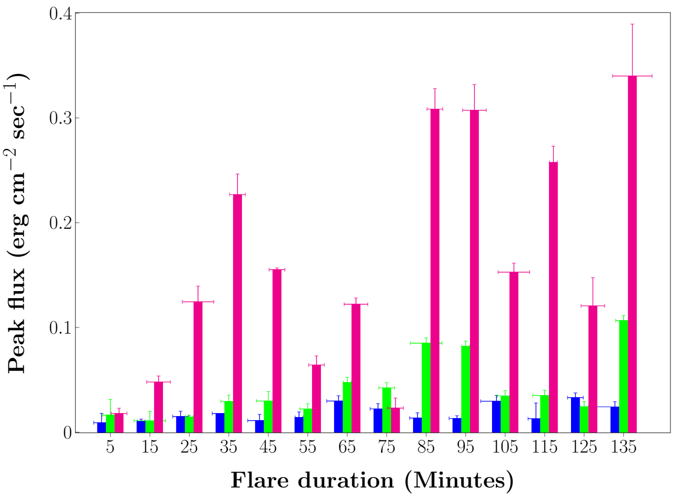

Fig. 1. SXR flare duration along X axis and peak flux along Y axes. The bars in blue are flares without CMEs, bars in green are flares with associated CMEs and bars in pink are flares associated with CMEs from the WW list. The error bar overlaid on each bar indicate the error in each bin.

It is argued that the accumulated energy is released in flares. Therefore, the difference between the duration of the flares associated with CMEs and the flares without CMEs is a measure of the energy enhancement that should trigger the CME in association with the flare. This is so if the CME is occurring due to energy crossing a threshold. In this context, we note that coronal loops may detach when filled with hot, dense plasma, and the detachment may lead to the consequent CME occurrence (Brosius and Holman 2012). Further, higher free energy may have a bearing in the occurrence of flares with CMEs (Lin 2004).

If energy enhancement is the sole factor in triggering a CME, the peak flux enhancement too will be following the same trend as duration enhancement. On the other hand, the difference in flare peak flux so obtained could be an indication of the sudden surge in the peak flux signalling a different phenomena such as the helicity expulsion in association with the CME.

We obtain the difference in flare duration between the flares associated with CMEs and flares not associated with CMEs from the previously obtained bins of 5 minutes duration. We obtain the peak flux difference similarly for the same bins.

We plot the association between the difference in duration and difference in peak flux in Fig.2(left). Similarly, we plot the association between the difference in duration and difference in peak flux for the flares without associated with CMEs and flares associated with CMEs from the WW list in Fig.2(right). The flares without associated CMEs are the same for both panels.

A good association between the difference in duration and difference in peak flux would have meant that the flare peak flux too varies in line with the flare duration. However, the lack of a good association resulting from the present analysis is an indication that the CME occurrence is due to a disturbance in the timescale of energy release (Kay et al. 2003).

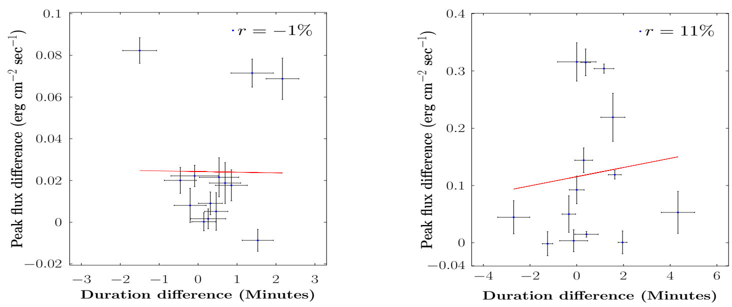

Fig. 2. The figure in the left indicates the association between the duration difference and the peak flux difference. The difference is between the flares associated with CMEs and flares without associated CMEs. The figure in the left are flares associated with CMEs from the simple temporal association and flares without associated with CMEs. The figure in the right are flares associated with CMEs from the WW list and flares without associated with CMEs. The error bar overlaid on each bar indicate the error in each bin. Red continuous line indicates linear least squares fit. Correlation coefficients are shown as inset values in each figure.

The ratio of duration of flare between flares with CME and without CME is another measure of energy enhancement. Similarly, the ratio of peak flux values too is a measure of enhancement of energy if the higher peak of flares with CMEs is due to higher accumulated energy in such events. Hence, their association, or the lack of it, conveys specific message. In Fig.3(left) and Fig.3(right), we consider the association between the ratios of the flare durations and ratios of peak fluxes.

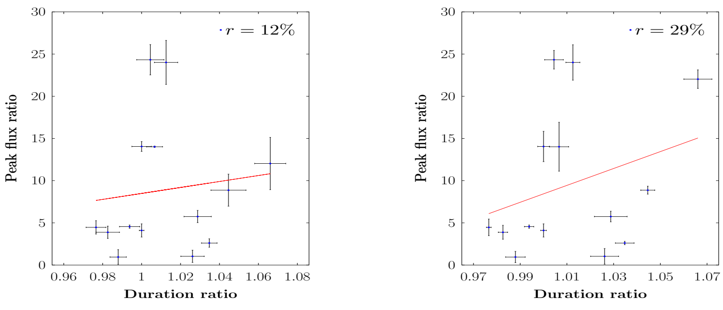

Fig. 3. The figures indicate the association between the duration ratio and peak flux ratio. The ratio is between flares associated with CMEs and flares without associated CMEs. The figure in the left are flares associated with CMEs from the simple temporal association and flares without associated with CMEs. The figure in the right are flares associated with CMEs from the WW list and flares without associated with CMEs. The error bar overlaid on each bar indicate the error in each bin. Red continuous line indicates linear least squares fit. Ratios being quantities without dimensions, no units are shown. Correlation coefficients are shown as inset values in each figure.

We find that there is a rather poor association between the ratio of flare duration and ratio of peak flux. These results clearly point to the perturbance in the flux emission timescale in the case of flares associated with CMEs suggesting these flares as a distinct class of events.

Fig.2 and Fig.3 represent the twin measure of the role played by helicity expulsion that result in the perturbance in the timescale of release of energy in flares associated with CMEs indicating the distinctness of such flares compared to flares without CMEs.

4. Discussion and conclusion

Helicity has been reported to be playing a decisive role in the emission of flares with higher peak flux and an associated CME. Significantly higher estimated magnetic helicity prevails in the flare-CME ARs than the ARs where flares occur with no CME (Nindos and Andrews 2004). Filament eruptions have been reported to be occurring with a strong temporal correlation with helicity transport from the photospheric magnetic shear motions and emergence (Romano et. al. 2003). The evolution speed of an eruptive filament has been temporally coinciding with the transport rate of magnetic helicity of its host AR (Moon et. al. 2003), which reveals that the filament eruption onset commenced about 10 minutes before the starting of the impulsive variation of the magnetic helicity change rate. The impulsive injection of magnetic helicity is positively correlated with the X-ray peak flux of the associated flare (Moon et al. 2002a).

The solar magnetic field's helical structure has been observed in photospheric magnetic fields (Pevtsov and Canfield 1999, Zhang et. al. 2008), chromospheric Hα images (Chae 2000), and coronal X-ray images (Canfield and Pevtsov 1999). These helical structures are believed to be more likely to erupt leading to flares and CMEs (Canfield and Pevtsov 1999). The magnetic helicity is the signature of the helical structure of the magnetic field, which is defined as the sum of the linkage and twist of field lines. It is known that chromospheric and coronal tracers enables the measurement of free energies from different EUV (extreme ultra-violet) and UV (ultra-violet) wavelengths that show up as vertical electric currents manifested in the form of helically twisted loops (Aschwanden 2015).

In a study involving a few X-class and M-class flares, two flares are found to be associated with helicity changes (Hartkorn and Wang 2004, Moon et al. 2002b). The temporal variation of dH/dt (rate of change of helicity with time) has been found to be correlated well with the microwave burst which occurred in an isolated AR NOAA 10930 (Zhang et. al. 2008).

Further, the total unsigned magnetic flux of the host AR has been found to be higher compared to the visible solar disk for CME associated flares, whereas the total flux bears no dependence to the flare type. This is an indication of the prominent role of helicity in causing the CMEs and the associated higher peak flux in such flares. It is also found that dH/dt variations have close association to the flare properties and the host AR (Zhang et. al. 2009). This study has classified the event as type I flare when associated with impulsive injection of dH/dt, and flare without appreciable injection of helicity as type II flare.

The CME association is indicated with flares of long duration where multiple destabilizations of filaments occur (Zuccarello et. al. 2011) in contrast to non-CME flares where the same is absent (Choudhary and Moore 2003). This may be regarded as a strong indication of flare peak flux being an important attribute of the eruption of CME compared to duration of the flare. This implication is evident because flares associated CMEs attain higher peak flux (Suryanarayana and Balakrishna 2017) and the flare associated with CME attains its peak flux a few hours after the rise in magnetic flux which was preceded by accumulation of peak helicity and the destabilization of the associated filament (Zuccarello et. al. 2011). Therefore, it is possible that the peak flux of the flare is a representation of the AR characteristics, so that enhanced peak flux is quite often the case when an associated CME occurs.

Hence, among other distinguishing features, the flare peak flux stands out as a decisive parameter to conclude that the flares occur in association with CMEs or without association with CMEs. So, the SXR peak flux enhancement is the criterion that constitutes two classes of flares: CME flares and non-CME flares.

It has been reported that an intense SXR flare would not necessarily amount to an associated CME (Nindos and Andrews 2004). However, the present study indicates that most often a flare with higher peak flux is a necessary pre-requisite for a CME to occur, compared to a flare of similar duration without an associated CME. Hence, the present study is important in terms of statistically presenting a compelling case for classification of flares as comprising of two classes especially since the underlying condition is one of whether the AR contains significant helicity and its expulsion.

In terms of application, this conclusion may lead to arriving at projections of a flare duration dependent peak flux estimates for predicting potential flare candidates for CME occurrences. We will report the results of the same in a future paper.

References

Andrews, M. D., 2003, *Sol. Phys.*, 218: 261-279

Aschwanden, M. J., 2013, *Sol. Phys.*, 287:369-389

Aschwanden, M. J., 2015, *ApJ Letters*, 804:L20 (6pp)

Brosius, J. W. and Holman, G. D., 2012, *A&A*, 540, A24

Burkepile, J. T., Hundhausen, A. J., Stanger, A. L., St.Cyr, O. C., and Seiden, J. A. 2004, *J. Geophys. Res.*, Vol. 109, A03103, 16pp

Canfield, R. C., and Pevtsov, A. A. 1999, A&A, in *Magnetic Helicity in Space and Laboratory Plasmas*, ed. M. R. Brown, R. C. Canfield and A. A. Pevtsov (Geophys. Monogr. 111; Washington, DC: AGU), 197

Chae, J. 2000, *ApJ*, 540, L115

Chen, A., and Zong, W. 2009, *RAA*, Vol. 9, No.4, 470-474

Chen, C., Wang, Y., Shen, C., Ye, P., Zhang, J., and Wang, S. 2011, *J. Geophys. Res.*, Vol. 116, A12108, 15pp

Cheng, X., Zhang, J., Ding, M. D., and Poomvises,W. 2010, *ApJ*, 712:752-760

Cheng, X., Zhang, J., Ding, M. D., Guo, Y., and Su, J. T., 2011, *ApJ*, 732:87 (8pp)

Choudhary, D. P., and Moore, R. L., 2003, *Geophys. Res. Lett.*, Vol.30, No.21, 2107

Gopalswamy, N., Mäkelä, P., Yashiro, S., Lara, A., Xie, H., Akiyama, S. and MacDowall, R. J. 2018, *ApJ. Letters*, 868:L19 (8pp)

Gopalswamy, N., Mäkelä, P., and Yashiro, S., 2019, *Sun and Geosphere*, 14/2: 111-121

Green, L. M., Harra, L. K., Matthews, S. A., and Culhane, J. L., 2001, *Sol. Phys.*, 200, 189-202

Green, L. M., Démoulin, P., Mandrini, C. H. and Van Driel-Gesztelyi, L., 2003, *Sol. Phys.* 215: 307-325.

Guo, J., Zhang, H. Q., and Chumak, O. V., 2007, *A&A*, Vol. 462, 1121-1126

Harrison, R. A., 1991, *Adv. Space Res.*, 11, 25-36

Harrison, R. A., 1995, *A&A*, 304, 585-594

Hartkorn, K., and Wang, H. M. 2004, *Sol. Phys.*, 225, 311

Hinterreiter, J., Veronig, A.M., Thalmann, J.K., Tschernitz, ·J., and Pötzi, · W. 2018, *Sol. Phys.*, 293:38

Hundhausen, A. J. 1997, in *Coronal Mass Ejections*, eds. N. Crooker, J. A. Joselyn, and J. Feynmann (Washington: AGU)

Jain, J., Aggarwal, M. and Kulkarni, P. *RAA*, 2010, Vol.10, No.5, 473-483

Kahler, S. W., Sheeley, N. R., Jr., and Liggett, M. 1989, *ApJ*, Vol. 344, 1026-1033

Kay, H. R. M., Harra, L. K., Matthews, S. A., Culhane, J. L., and Green, L. M. 2003, *A&A* 400, 779-784 (2003)

Lin, J. 2004, *Sol. Phys.*, 219, 169

Liu, R., Liu, C., Park, S., and Wang, H., 2010a, *ApJ*, 723:229-240

Liu, Y., Davies, J. A., Luhmann, J. G., Vourlidas, A., Bale, S. D., and Lin, R. P. 2010b, *ApJ Letters*, 710:L82-L87

Moon, Y. J., Chae, J. Y., Choe, G. S., Wang, H. M., Park, Y. D., Yun, H. S., Yurchyshyn, V., and Goode, P. R. 2002a, *ApJ*, 574, 1066

Moon, Y. J., Chae, J. Y., Wang, H. M., Choe, G. S., and Park, Y. D. 2002b, *ApJ*, 580, 528

Moon, Y. J., Chae, J., and Park, Y. D. 2003, *J. Korean Astron. Soc.*, 36, 37

Nindos, A., and Andrews, M. D., 2004, *ApJ*, 616:L175-L178

Nitta, N.V. Aschwanden, M.J. Freeland, S.L., Lemen, J.R., Wülser, J.-P., and Zarro, D.M., 2014, *Sol. Phys.*, 289:1257-1277

Pevtsov, A. A., and Canfield, R. C. 1999, in *Magnetic Helicity in Space and Laboratory Plasmas*, ed. M. R. Brown, R. C. Canfield, and A. A. Pevtsov (Geophys. Monogr. 111; Washington, DC: AGU), 103
Romano, P., Contarino, L., and Zuccarello, F. 2003, *Sol. Phys.*, 218, 137
Sheeley, N., Howard, R. A., Oomen, M. J., and Michels, D. J. 1983, *ApJ*, Vol. 272, 349-354.
Su, Y., Van Ballegooijen, A., and McCaughey, J. 2007, *ApJ*, 665:1448Y 1459,
Suryanarayana, G.S., 2012, *NewA*, 17, pp.117-129
Suryanarayana, G.S., and Balakrishna, K. M., 2017, *RAA*, Vol. 17 No. 1, 7 (6pp)
Suryanarayana, G.S., and Balakrishna, K. M., 2018, *Adv. Space Res.* Vol.No.61, p.2482-2489
Tandberg-Hanssen, E., and Emslie, A.G.: 1988, *The Physics of Solar Flares*, Cambridge, University Press, Cambridge/New York. Chapter9
Wang, Y., and Zhang, J., 2007, *ApJ*, 665:1428-1438
Yashiro, S., Akiyama, S., Gopalswamy, N. and Howard, R. A. 2006, *ApJ*, 650: L143-L146
Zhang, Y., Liu, J. H., and Zhang, H. Q. 2008, *Sol. Phys.*, 247, 39
Zhang, Y., Tan, B., and Yan, Y., 2009, *ApJ*, 704:1622-1627
Zuccarello, F., Contarino, L., Farnik, F., Karlicky, M., Romano, P. and Ugarte-Urra, 2011, *A&A* 533, A100